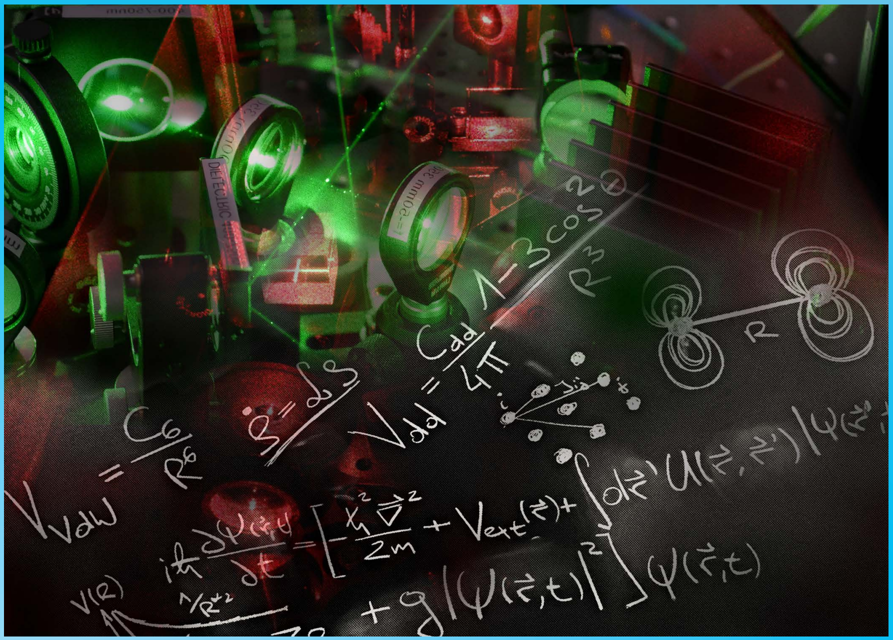
Center for Astrophysics| Harvard & Smithsonian
ITAMP
60 Garden Street
Cambridge, MA 02138 USA

Unravelling quantum many-body physics with long-range interacting platforms

May 10 - 12, 2023

Organizers

Francesca Ferlaino *(Innsbruck)*, **Benjamin Lev** *(Stanford)*
Simeon Mistakidis *(ITAMP)*, **Stefan Ostermann** *(Harvard)*



Credit: Simeon Mistakidis and Stefan Ostermann

Phillips Auditorium
Center for Astrophysics|Harvard & Smithsonian 60 Garden St. Cambridge, MA 02138

***ITAMP is funded by the National Science Foundation**

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Notes

ITAMP began life in 1989 at the Harvard-Smithsonian Center for Astrophysics. It is the only theoretical AMO "user facility" in the United States. It hosts workshops (3-days), and visiting fellows (short- and long-term), sponsors a flagship speaker series, the Joint Quantum Science seminars, with HQI in the Physics Department, and a rigorous postdoctoral program. ITAMP workshops are recorded and avaliable on the ITAMP YouTube channel. There are on average 4-5 workshops each year. A Call for Proposal to organize workshops and a list of workshops are available at http://itamp.harvard.edu. The postdoctoral program has been a recognized success, placing energetic fellows into junior positions at universities and national labs.

ITAMP thrives in the larger Cambridge-area AMO physics ecosystem, drawing upon the considerable depth and breadth of experimental expertise. The mission of ITAMP continues to be in furthering the cause of theoretical AMO physics by providing resources, centrality of location, and scientific and administrative expertise, to enhance collaborative efforts between theory and experiment, and to be broad in advocating for theoretical AMO.

H. Sadeghpour

The focus of this workshop is on platforms where long-range interactions in quantum many-body atomic and molecular gases dominate and on engineering such interactions with classical and quantum light, as in cavity QED and with Rydberg atoms. The observation of exotic quantum phases, such as droplets and supersolids have stimulated considerable interest and activity for possible applications in simulation of quantum systems, collective phenomena and entanglement. The traditional setting of ITAMP workshops allows for extensive collaborative encounters among aspiring researchers and leading experts in the field.

Organizers:

Francesca Ferlaino (Innsbruck)

Simeon Mistakidis` (ITAMP)

Benjamin Lev (Stanford)

Stefan Ostermann (Harvard)

Instructions for Reimbursement Forms

If you have been promised support to help cover your expenses, the following forms will be required paperwork for your reimbursement. Please, only use the attached forms if you have already received an offer of support. If you feel there has been a mistake or are unsure about your support, please ask and we can assist you.

We will only need receipts that will total up to your promised support in your invitation letter. If your receipts total over that amount, you will simply just be reimbursed up to that promised amount. Please submit all travel reimbursements within the 45 days after workshop has ended.

Here are the directions for filling out the following forms.

1) The Non-Employee Reimbursement Form.

This form is submitted to the University and must be completely filled out. This form can be found at https://travel.harvard.edu/files/procurement-travel/files/nonemployee_reimbursement_form_digital_ signature_v1.pdf?m=1617208983. When completing this form please leave the following section blank; General Description/Business Purpose, as we will fill this out for you. Please remember to sign where it is indicated “Signature of Reimbursee”.

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In order for reimbursement, you will be sent an invitation email to be set up into our Buy2Pay system. Once you complete the setup in our system, we can begin the reimbursement process.

Please be patient as the reimbursement setup and payment process may take some time. Thank you

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Buses to Watertown and Belmont are #71, #73
Harvard Square to Boston: Red Line Train to Park Street Station
Harvard Square to Airport: Red Line Train to South Station. Take the Silver line to Logan Airport. Silver line stops at all terminals. To see the schedule of buses visit http://www.mbta.com/schedules_and_maps/bus/

Taxicabs
Ambassador: 617 492-1100 Yellow: 617 547-3000

Dining around ITAMP

Near the Observatory

Sarah's Market, 200 Concord Ave.

The Village Kitchen, 359 Huron Ave.
House of Chang, 282 Concord Ave.
Trattoria Pulcinella, 147 Huron Ave.
Armanado's Pizza, 163 Huron Ave.
Hi-Rise Bread CO, 208 Concord Ave.
Formaggio Kitchen, 244 Huron Ave

Massachusetts Ave.

Chang-Sho, 1712 Mass. Ave.
Simons Coffee House, 1736 Mass. Ave.
Nirvana The Taste of India 1680 Mass Ave
Stone Hearth Pizza Co., 1782 Mass.Ave.
Super Fusion, 1759 Mass. Ave.
Cambridge Common, 1667 Mass Ave.
Lizard Lounge, 1667 Mass. Ave.

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Internet Access

Most wireless devices will connect to the "Harvard Guest" account. This works fine and there is no paperwork involved in getting internet access. Other connections such as edurom are available.

Copiers/Faxing and Phone Access

Copy Machines are located throughout the building. Should you need access to a copier please see someone at ITAMP.

Telephone System

To call outside the University you must dial 9 before the number. The University prefix three digits are 495 and 496. To dial on campus, you simply need to dial the "5" or "6" and the last four digits. For example, ITAMP Admin office s number is 617-495-9524. You can dial 5-9524 to call internally. The Institute is not permitted to pay for long distance calls.

Susanne Yelin

Harvard University

"Superradiance in arrays: new insights and applications"

Super- and subradiance are examples of cooperative phenomena. While the fundamental aspects are subject of intense studies, there are now also many possible applications that benefit from the nonlinearity and intrinsic quantum nature of the system. These include quantum information processing, metrology, and nonlinear single-photon techniques. I will introduce the basic physics aspect of such a system and introduce some applications.

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Unravelling quantum many-body physics with long-range interacting platforms

Wednesday, May 10, 2023

Chair: Benjamin Lev

8:30-9:00 am	Welcome/Refreshments
9:00-9:40 am	Markus Greiner
9:40-10:20 am	Luis Santos
10:20-10:50 am	Coffee Break
10:50-11:30 am	Tilman Esslinger
11:30-12:10 pm	Blair Blakie
12:15-2:00 pm	Lunch (Served at The Library)

Chair: Luis Santos

2:00-2:40 pm	Tilman Pfau
2:40-3:20 pm	Igor Lesanovsky
3:20-3:50 pm	Coffee Break
3:50-4:30 pm	Simeon Mistakidis
4:30-5:10 pm	Elena Poli
5:15-6:30 pm	Poster Session (Rotunda)

Thursday, May 11, 2023

Chair: Ana-Maria Rey

8:30-9:00 am	Refreshments
9:00-9:40 am	Andreas Hemmerich
9:40-10:20 am	Francesco Piazza
10:20-10:50 am	Coffee Break
10:50-11:30 am	Susanne Yelin
11:30-12:10 pm	Vladan Vuletic
12:15-2:00 pm	Lunch (Served at The Library)

Zoe Yan

Princeton University

"Measuring quantum correlations across multiple systems: bosonic dipolar molecules and programmable Fermi-Hubbard simulators"

Ultracold molecules and atoms have promising applications in the fields of quantum computing, simulation of many-body systems, and precision measurements. One outstanding challenge in the field is the detection of quantum correlations between molecules. The Princeton group has developed a novel apparatus for imaging single polar molecules, enabling the measurement of quantum correlations due to entanglement mediated by dipolar interactions. I will discuss our study of out-of-equilibrium dynamics in tunable quantum spin models and the evolution of spatial correlations during the thermalization process.

Next, I will report on recent progress in our Li-6 fermionic atomic microscope experiment, where we engineered the capability to study the triangular 2D Fermi-Hubbard model in a programmable optical lattice.

Valentin Walther

Purdue University

"Ménage à trois: Rydberg interactions beyond the binary limit"

Polarization forces are ubiquitous in nature, both in the animate as well as the inanimate world. Most often, these interactions are described as binary forces. In this talk, we will explore two systems that break this limit and reveal the importance of three-particle interactions.

In the first part, we will revisit the limit of binary interactions for lattice systems of Rydberg atoms. We will describe when the binary limit is valid and when additional terms must be considered. In particular, we will find special conditions near a Förster resonance where three-atom interaction can be significant. We will outline ongoing efforts to characterize the low-energy Hamiltonian and to understand the expected quantum behavior at and in the vicinity of these special conditions.

In the second part, we will discuss results on so-called Rydberg macrodimer states, diatomic molecules of micron extent that have recently been observed as loss series in atomic lattice experiments. We will describe their optical response, from simple optical resonances in the weak light-matter coupling limit to the emergence of Fano-type lineshapes when macrodimers hybridize with continuum states under increased coupling strength. We will then discuss the limit of very strong coupling, where new molecular bound states emerge, forming a three-atom molecular wave function, which we term "microtrimeron". We will compare our theoretical results with recent experimental measurements.

Chair: Tilman Pfau

2:00-2:40 pm	Stephanie Reimann
2:40-3:20 pm	Valentin Walther
3:20-3:50 pm	Coffee Break
3:50-4:30 pm	Stefan Ostermann
4:30-5:10 pm	Ronen Kroeze
5:10-5:50 pm	Stuart Masson
6:00-7:00 pm	Poster Session

Friday May 12, 2023

Chair: Valentin Walther

8:30-9:00 am	Refreshments
9:00-9:40 am	Ana-Maria Rey
9:40-10:20 am	Zoe Yan
10:20-10:50 am	Coffee Break
10:50-11:30 am	Kang-Kuen Ni
11:30-12:10 pm	Sarang Gopalakrishnan
12:15-2:00 pm	Lunch (Served in the Lobby)
2:00 pm	Adjourn

Blair Blakie

University of Otago

"Supersolidity of a dipolar Bose gas in an infinite tube: ground states and excitations"

I will discuss the results of a theoretical investigation into the supersolid state of a dipolar quantum Bose gas confined within an infinite tube potential [1-3]. This system serves as a thermodynamic idealization of cigar-shaped dipolar Bose gases, which have been utilized in recent experiments to prepare supersolids [4]. Our study presents phase diagrams as a function of the average linear density and s-wave scattering length, wherein we have observed that the supersolid transition exhibits both continuous and discontinuous regions as the average density varies. Additionally, we have explored the excitations of the system, which reveal softening of roton-like and Higgs-like modes at the continuous transition [7], and analyzed the behavior of sound speeds. Our results show that the sound speeds and compressibility exhibit a discontinuity at the transition, indicating a second-order phase transition. We have also compared our full numerical results [2,3] with those of a simpler reduced theory [1], which describes the transverse part of the field variationally (see also [5,6]).

References

[1] P. B. Blakie, D. Baillie, L. Chomaz, and F. Ferlaino, Supersolidity in an elongated dipolar condensate, Physical Review Research 2, 043318 (2020).
[2] Joseph C. Smith, D. Baillie, and P. B. Blakie, Supersolidity and crystallization of a dipolar Bose gas in an infinite tube, Physical Review A 107, 033301 (2023)
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[6] Tobias Ilg and Hans Peter Büchler, Ground-state stability and excitation spectrum of a one-dimensional dipolar supersolid, Physical Review A 107, 013314 (2023)
[7] J. Hertkorn, F. Böttcher, M. Guo, J. N. Schmidt, T. Langen, H. P. Büchler, and T. Pfau, Fate of the Amplitude Mode in a Trapped Dipolar Supersolid, Physical Review Letters 123, 193002 (2019)

Vladan Vuletic

Massachusetts Institute of Technology

"Light-induced all-to-all interactions for quantum metrology with atoms"

Linear quantum measurements with independent particles are bounded by the Standard Quantum Limit (SQL) that can be overcome by inducing entanglement between the particles. In cold-atom systems, many-body entanglement can be induced by the collective interaction of the atoms with photons in a cavity mode. However, the metrological gain from entanglement is often limited by the final state readout rather than the state preparation, especially for more complex entangled many-body states with non-Gaussian probability distributions. An alternative is to use a time-reversal protocol to amplify small displacement of the entangled state. We implement such a time-reversal protocol through a controlled sign change in many-body Hamiltonian of atomic spins coupled to an optical cavity. We also use the time-reversed Hamiltonian to experimentally investigate the relation between quantum information scrambling, out-of-time-order correlators and metrological gain.

Luis Santos

University of Hannover

"Dipolar gases: from supersolids to non-equilibrium dynamics in polar lattice gases"

Ultracold dipolar gases, formed by atoms or molecules with strong dipole-dipole interactions, open many intriguing novel possibilities. I will first focus on dipolar Bose-Einstein condensates, and in particular on dipolar supersolids. I will discuss possible strategies for creating and observing vortices in the supersolid phase, and comment on droplet catalyzation, two-fluid supersolidity, and self-bound crystals in dipolar mixtures. In the second part of the talk, I will move to dipolar lattice gases. I will first comment on extended Hubbard models, showing how the strong inter-site interactions lead to a peculiar dynamics of inter-site dimers in one- and two-dimensional lattices, and result in Hilbert-space shattering and interaction-induced localization in absence of disorder. I will discuss how the latter can be affected by the transversal confinement and the presence of dipole-assisted hopping. Finally, I will comment on spin models formed by pinned polar molecules, which open interesting possibilities for the study of disordered models with power-law hops, and pair-creation models in bilayer set-ups.

Tilman Esslinger

ETH Zurich

"Self-oscillating many-body states driven by dissipative coupling to a cavity"

A paradigmatic model for matter-light interaction is the coupling between an off-resonantly illuminated Bose-Einstein condensate and the vacuum mode of an optical cavity. Remarkably, with increasing coupling the softening of a low-energy density wave results – at a critical value – in a self-organization phase transition. Engineering a two-component condensate, we created a model system, in which two softened modes compete with each other. By dissipatively coupling the resulting density and spin modes, we entered a regime in which the system undergoes a self-oscillation between the two modes [N. Dogra, et al. Science, 366, 1496 (2019)]. Creating a coupling geometry that accommodates two density modes with different centers of inversion symmetry, we discovered that the self-consistent oscillation of the condensate gives rise to the time periodic light-field structure of a topological pump [Dreon et al., Nature, 608, 494 (2022)].

Sarang Gopalakrishnan

Princeton University

"Sequential preparation of highly entangled states"

Matrix-product states can be sequentially generated by collecting the radiation coming out of an open quantum system. The Hilbert space dimension of the open system maps onto the bond dimension of the matrix-product state. Here we generalize this construction to settings where the open quantum system is infinite-dimensional, and identify a class of highly entangled states that can be efficiently generated. These states include the well-known Fredkin and Motzkin states as special cases. The "state-generating machines" we describe are intimately related to push-down automata, as we will discuss.

Ana-Maria Rey

JILA

"Emergent entangled dark states from superradiance emisson in multi-level atoms"

Subradiant states that emit light slower than independent atoms because of quantum interference have attracted widespread interest owing to their potential applications in quantum technologies. A long-standing challenge is finding simple ways to prepare a target many-body subradiant state that is also highly entangled. Optical cavities are natural candidates for creating highly entangled states since they have demonstrated the capability to create collective quantum many-body states with scalable entanglement. However, in generic atom-cavity experiments with two-level atoms, collective (i.e., fully symmetric) states are typically superradiant. i.e. emit light at a rate faster than independent atoms. In this talk I will discuss our proposal to use multilevel atoms coupled to a cavity to create dark states with scalable squeezing. Our findings are readily testable in alkaline-earth-like atoms trapped in optical cavities and could be used as pathways for quantum-enhanced sensing of optical phases in atomic clocks.

Stephanie Reimann

Lund University

"Persistent currents and vortices in binary and dipolar BEC's – from many atoms to the few-body limit"

A dipolar Bose-Einstein condensate that is set rotating in a toroidal geometry may act in distinctly different ways, depending on whether it is in a superfluid or in the supersolid phase. It can support a supersolid persistent current that in part consists of states where a fraction of the condensate mimics solid-body rotation in a direction opposite to that of a vortex. Furthermore, a rotating toroidal supersolid may show hysteretic behavior that is qualitatively different depending on the superfluid fraction of the condensate [1]. In this talk will discuss our recent work [2] on stacked droplets in anti-dipolar condensates, which offer intriguing possibilities to investigate vorticity and persistent flow in a setting that is rather different from the typical filament structures. The presence of a vortex line impacts on the phase transition into the supersolid region. I will also give an outlook how this setup will be used to study persistent current and distribution of angular momentum in the transition to the supersolid regime [3].
In binary bosonic mixtures, for equal short-range intra-component interactions but an unequal number of atoms in the two components, there is an excess part that cannot bind to a droplet. Imposing confinement, the droplet then becomes amalgamated with the residual condensate. I will discuss the rotational properties of such a compound system which show that the residual condensate can carry angular momentum even in the absence of vorticity. In contradiction to the intuitive idea that the superfluid fraction of the system would be entirely made up of the excess atoms not bound by the droplet, this fraction is found to be higher than what one would expect, intriguingly mimicking a "one-droplet" analog to a supersolid [4].
I will also address the few-body limit of binary droplets in a diagonalization approach and show how the excitation spectra and ground-state pair correlations signal the self-binding [5] (in some analogy to our previous finding of few-body analogs of elementary modes to uncover fermion pairing fluctuations [6]).

The above work was performed in collaboration with K. Mukherjee, M. Nilsson Tengstrand, P. Stürmer, L. Chergui and T. Arnone Cardinale at Lund University, and partly within the collaborations in the works listed below.

Markus Greiner

Harvard University

"Dipolar quantum solids"

Long range and anisotropic interactions in Hubbard systems are expected to give rise to a wealth of strongly correlated quantum phases. In my talk I will present recent experiments in which we observe quantum phase transitions from superfluids to dipolar quantum solids in a cold-atom Hubbard optical lattice. Magnetic dipole-dipole forces between spin-polarized Erbium atoms give rise to coherent long-range interactions. By tuning the dipole orientation we can widely tune the anisotropy of the interaction and observe dipolar solids with stripe, checkerboard, and diagonal stripe order. Quantum gas microscopy enables us to study the quantum solids on a single site level. This work opens the door to microscopic quantum simulations of itinerant dipolar lattice systems.

Andreas Hemmerich

University of Hamburg

"Experimental realization of discrete and continuous time crystals in an atom-cavity platform"

I will discuss our recent experimental realizations of discrete and continuous time crystals using an all-to-all interaction between atoms in a Bose-Einstein condensate mediated by a high finesse optical cavity.

Elena Poli

University of Innsbruck

"Rotating dipolar quantum gases"

Since the first observation of a Bose-Einstein condensate (BEC) made of strongly dipolar quantum gases, these systems have proven to be a rich source of new and fascinating phenomena arising from the long-range and anisotropic dipole-dipole interaction. Here, we will present the latest results from our ultracold dipolar quantum gas research in Innsbruck, with a particular focus on the rotational properties of these systems in different phases. The presence of quantized vortices – topological defects of the condensate wavefunction characterized by a 2π phase winding around the vortex line –consists of one of the most distinctive manifestations of their superfluid nature. We report on the first experimental observation of quantized vortices in a strongly magnetic BEC of dysprosium atoms by stirring the gas through rotating the magnetic field, using a novel technique exploiting magnetostriction due to the dipole-dipole interaction [1]. We observed the vortex cores arrangement into stripes aligned along the magnetic field direction, an effect which becomes absent when turning the magnetic field parallel to the rotation axis. These results open the door for studying more complex phases of matter under rotation, such as dipolar supersolids states, that simultaneously manifest a crystalline order – typical of a solid – and superfluid properties. Indeed, recently observed two-dimensional supersolids [2, 3] pave the way to investigate the dynamical properties of the system during rotation.

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Francesco Piazza

MPKS Dresden

"The peculiarities of photon-mediated interactions and their effect on the Fermi surface"

Motivated by recent experimental developments both in solid state and ultracold-atomic systems, I will discuss a situation where photons confined within a cavity are strongly coupled to a Fermi surface. This realises a novel, low-energy, and finite-density version of quantum electrodynamics. I will show how novel scenarios for the emergence of macroscopically ordered phases of matter can arise, and how these can be drastically modified by preparing non-Gaussian states of light in the cavity.

Igor Lesanovski

University of Tuebingen

"Time-crystal phases, fluctuations and quantum correlations in spin-boson systems"

We investigate the creation and control of emergent collective behaviour and quantum correlations in spin-boson systems [1]. In particular, we consider the regime where few bosonic modes induce long-ranged interaction among spins. Such situation occurs, e.g., in emitter-waveguide systems or atoms held in a cavity. We begin by considering a minimal model of an emitter-waveguide systems, where the bosons can be integrated out yielding a so-called boundary time-crystal model [2]. We show how feedback, based on homodyne detection of photons emitted into the modes of a waveguide, allows to generate and control the time-crystal phase. Developing a theory for the dynamics of fluctuation operators [3] we quantify spin squeezing and fluctuations within the ensemble emitters, revealing critical scaling of the squeezing close to the transition to the time-crystal [2]. We moreover show that within the time-crystal phase fluctuation evolve under a non-Markovian dynamics [3]. Finally, we consider a scenario in which the bosonic modes are not integrated out. This yields novel non-equilibrium phases, such as a regime where time-crystal solutions and stationary states coexist.

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[2] G. Buonaiuto, F. Carollo, B. Olmos and I. Lesanovsky, Dynamical phases and quantum correlations in an emitter-waveguide system with feedback, Phys. Rev. Lett. 127, 133601 (2021)
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Stuart Masson

Columbia University

"Superradiance in ordered atomic arrays"

Collective phenomena are found in every branch of science; the behavior of the whole differs strongly from the behavior of the individual elements. In quantum optics, a hallmark example is Dicke superradiance. Here, a fully inverted ensemble of atoms emits a short and bright light pulse, known as the superradiant burst, that initially grows in intensity. This is in stark contrast to independent atoms which decay exponentially, emitting a pulse that monotonically decreases in time. Experiments in dense disordered systems have observed the superradiant burst, but there, inhomogeneous broadening plays a large role, making the systems hard to model or control. In contrast, ordered arrays have much lower inhomogeneity - atoms in the bulk all see the same set of neighbors - making them an ideal platform to study dissipative many-body physics. Here, we show the conditions under which such systems produce a superradiant burst. We go beyond two-level approximations, and demonstrate that long-wavelength transitions from ytterbium and strontium atoms can be used to observe such physics. Our work represents an important step in harnessing such systems to build quantum optical sources and as dissipative generators of entanglement.

Tilman Pfau

University of Stuttgart

"Quantum Optics based on dipolar interactions between hot atoms"

Electrical dipolar interactions between Rydberg atoms are so strong that even for thermal atomic vapor the Rydberg blockade can be observed via the single photon emission of a blockaded ensemble. Additionally, the light induced dipolar interaction between two level atoms, the so-called Lorentz-Lorenz shift, can be observed in very thin cells as a 2D geometry of interacting dipoles as well as in 1D geometries, which are realized in integrated nano-photonic slot waveguides. The latter leads to a substantial and observable Purcell enhancement of the blue shift at telecom wavelengths due to the dipolar interaction. As an outlook we present the concept of an optical single thermal atom detector based on a freestanding photonic crystal cavity that enhances the atom light coupling to the strong coupling regime. These examples of thermal atoms acting as a reconfigurable strongly nonlinear medium in integrated nano-photonic circuits show that quantum optical applications on the single photon level are within reach.

Stefan Ostermann

Harvard University

"Hardware-Efficient Quantum Simulation of Strongly Correlated Molecules and Materials with Rydberg Atom Arrays"

Simulations of quantum chemistry and quantum materials are among the most important potential applications of quantum information processors. However, realizing practical quantum advantage for problems like the accurate calculation of molecular energies using the currently known methods is a challenging task. In this talk, I will introduce a recently developed simulation framework, which combines classical computational chemistry techniques with hardware-efficient quantum simulation to study the properties of molecules and materials with strong correlations. Our approach focuses on a class of systems described by effective spin Hamiltonians that can be efficiently computed from the full electronic structure problem using classical electronic structure methods. As such, we develop a protocol for simulating dynamics of the resultant spin-Hamiltonians in a hardware-efficient manner using reconfigurable neutral atom arrays and multi-qubit entangling operations. We further present a suite of algorithms for extracting detailed spectral information from time-dynamics, through snapshot measurements and ancilla-assisted control. This enables us to compute quantities relevant for characterizing material properties, including excitation energies and finite-temperature susceptibilities. Our approach also leverages state-of-the-art ground state optimization methods, ranging from tensor networks to short-depth quantum circuits, which can be used as a variational ansatz for the initialization of the dynamics. As a proof of concept, we apply this methodology to analyze organometallic catalysts and single-molecular magnets and propose near-term experiments for simulating 2D magnetic materials.

Simeon Mistakidis

ITAMP

"Phase diagram and dynamics of dipolar BECs exposed to a rotating magnetic field"

We will discuss the static properties and the nonequilibrium dynamics of dipolar Dysprosium Bose-Einstein condensates subjected to a fastly rotating external magnetic field. Relying on the extended Gross-Pitaevskii framework, we account for quantum fluctuations and map out the underlying phase diagram with respect to atom number and relative interaction strengths for various field orientations. Tuning the contact interaction or field orientation allows transitions from a superfluid to a supersolid and then to arrays of dipolar droplets characterized by a non-vanishing global phase coherence. For field orientations larger than the magic angle (anti-dipolar regime) only the superfluid and the single droplet persist. These phases occur both in quasi-1D and quasi-2D geometries. Following interaction quenches, across the aforementioned phase transitions, we observe the dynamical nucleation of supersolids or droplet lattices. The inclusion of three-body losses leads to self-evaporation of the ensuing structures,while the rotating magnetic field enables, for fixed values of the relative interactions, an enhancement of the droplet lifetimes.

Ronen Koreze

Stanford University

"Studying replica symmetry breaking with a confocal cavity"

Optical cavity QED provides a versatile platform with which to explore quantum many-body physics in driven-dissipative systems. Multimode cavities are particularly useful for exploring beyond mean-field physics. Confocal cavities host all-to-all, sign-changing, photon-mediated spin interactions that enable study of spin glasses in a quantum optical setting. Realizing a transverse field Ising model with quantum spins, we simulate the effective dynamics as the system is pumped through the Ising transition. By studying individual replicas as quantum trajectories monitored under continuous measurement, we demonstrate that the system can enter a spin glass regime with replica symmetry breaking (RSB). A Parisi-like overlap distribution is found from the RSB that emerges via dissipation of cavity light and entanglement near the phase transition.

Experimentally, we program fully connected interaction graphs between multiple BECs located inside the cavity. This realizes an anisotropic XY-model using the density wave phase of each BEC as pseudospin degree of freedom. By using the confocal cavity as an active quantum gas microscope, where light simultaneously mediates the interaction and images the spin state, we microscopically study the model's magnetic phases. We observe two low-temperature ferromagnetic phases, and a spin glass phase that hosts vector RSB. These results enable further microscopic study of associative memories and spin glass physics.

Kang-Kuen Ni

Harvard University

"Entangling single molecules through dipolar exchange interactions"

Generating entanglement on-demand is a key ingredient to harness molecular resources for quantum simulation and computation. We introduce two different approaches to gain single particle and quantum state control of molecules in an optical tweezer array. The new techniques allow us to isolate two molecular rotational states as two-level systems for qubits. In NaCs molecules, full state control including their motional states have been achieved. In order to preserve coherence of the qubits, we develop magic-ellipticity polarization trapping to reduce lightshift sensitivity by 1,000. In CaF molecules, without the need of motional ground-state cooling yet, but taking advantage of the resonant dipolar interaction of molecules, we entangle them with single site addressability. In combination, these recent advances allow molecular quantum systems to be programmable.